A Lake Trout Restoration Plan for Lake Michigan, 2005-2020

Charles R. Bronte[1], Charles C. Krueger[2], Mark E. Holey[1], Michael L. Toneys[3], Randy L. Eshenroder[2], and Jory L. Jonas[4]

[1]U.S. Fish and Wildlife Service
Green Bay Fishery Resources Office
2661 Scott Tower Drive, New Franken, WI 54229

[2]Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 209, Ann Arbor, MI 48105

[3]Wisconsin Department of Natural Resources
110 South Neenah Avenue, Sturgeon Bay, WI 54235

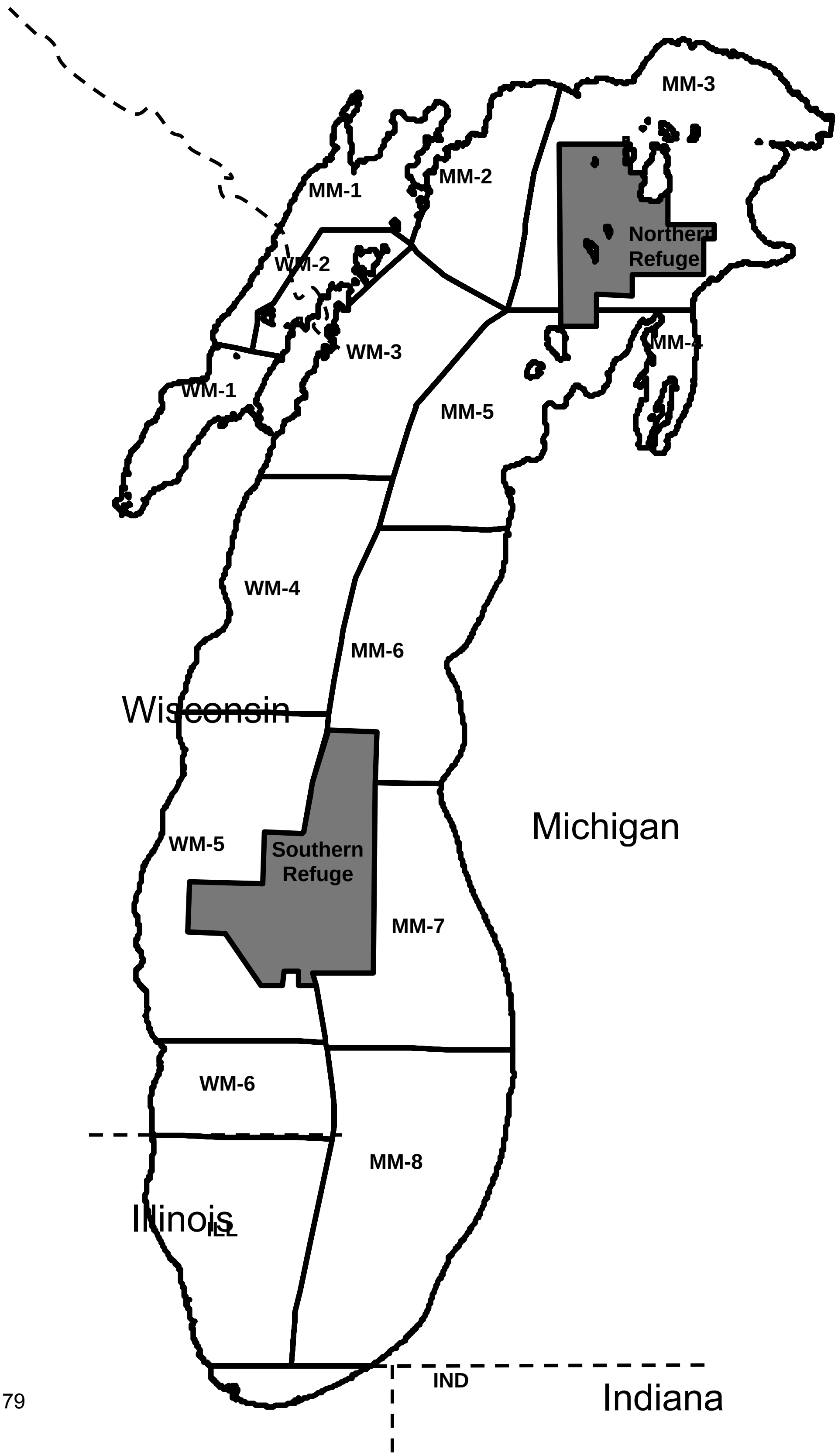
[4]Michigan Department of Natural Resources
Charlevoix Great Lakes Station, 96 Grant Street
Charlevoix, MI 49720

In fulfillment of a charge from the Lake Michigan Committee to the Lake Michigan Lake Trout Task Group

Table of Contents

Abstract - Over the past 40 years efforts to restore the lake trout (*Salvelinus namaycush*) populations in Lake Michigan have met with limited success due to inadequate levels of stocking, inappropriate stocking practices, excessive fishing mortality, and interactions between lake trout and native and non-native species. Based on an analysis of these impediments the plan was revised as set forth here. The goal of the revised plan is to reestablish a diversity of lake trout populations that are composed predominately of wild fish and that sustain desirable fisheries, and that by 2035, to have wild fish comprise 75% or more of the population of age-10 and younger in specific deep and shallow-water habitats. This plan shifts stocking to priority areas of limited geographic extent that have the best reproductive habitat and where fishing is minimized. In these limited areas, hatchery-reared fish will be concentrated to provide a sufficient density of adults for successful reproduction and to reestablish lake trout as a dominant local predator. Morphotypes introduced from Lake Superior into deep, offshore waters are expected to augment the population of lean lake trout in shallow-water. Continued control of fishing and increased control of sea lamprey populations are needed to achieve the population densities required for sustained natural reproduction. Progress towards achievement of the goal and the results assessments will be reviewed annually and reported.

Figure 1. *Statistical districts and refuge areas in Lake Michigan.*



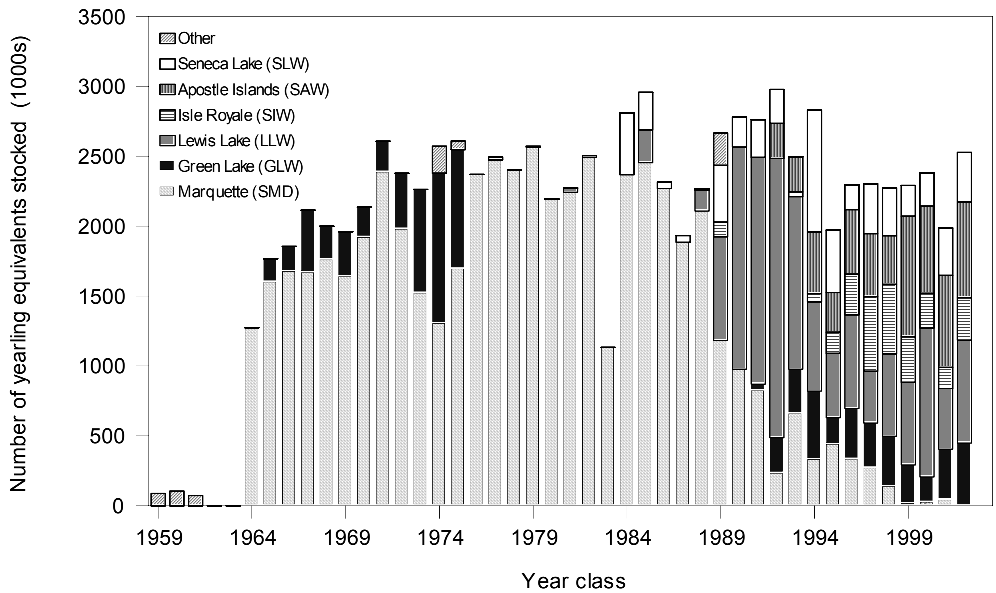
Introduction

Historical Background of Lake Trout Restoration

Lake Michigan contained the largest lake trout (*Salvelinus namaycush*) population and fishery in the world prior to the influences of over fishing, sea lamprey (*Petromyzon marinus*) predation, alewife invasion, and habitat degradation (Hile et al. 1951; Eschmeyer 1957; Wells and McClain 1973; Holey et al. 1995; Eshenroder and Amatangalo 2002). By the early 1950s all lake trout populations and the diversity of forms adapted to specific areas (Brown et al. 1981) were gone, sport and commercial fisheries had collapsed, and Lake Michigan was left without its primary native predator. In addition, populations of lake herring (*Coregonus artedii*), one of the major prey species for lake trout, were also declining and being replaced by non-native alewife (*Alosa psuedoharengus*) and rainbow smelt (*Osmerus mordax*).

Lake trout restoration efforts in Lake Michigan began in 1965 with widespread stocking of yearling lake trout produced mostly by federal hatcheries. Fish managers assumed that these hatchery-reared fish would find and spawn on appropriate habitat, and that their young would repopulate the lake. These stocked fish survived well but little natural reproduction was detected. Concurrently, the introduction of Pacific salmon (*Oncorhynchus* sp.) by the states (Kolcik and Jones 1999), which was aimed at reducing alewife populations, fueled the development of popular and economically valuable sport fisheries, which also harvested lake trout. The increased harvest by sport fisheries, combined with targeted and incidental commercial harvest and lamprey predation, led to increased mortality on stocked lake trout such that the viability of the restoration effort was questioned (Holey et al. 1995). A new rehabilitation plan was developed by 1985 which adopted the long-range goal “of a self-sustaining lake trout population, able to yield an annual harvest projected conservatively at 500-700 thousand fish weighting 2.5

million lb." (LMLTTC 1985). In the 1985 plan, lake trout restoration efforts became better focused and coordinated by 1) stocking promising strains at selected densities in defined restoration zones, 2) establishing two large refuges (Figure 1) that were intended to protect stocked fish from exploitation, 3) recommending a maximum-mortality target of 40%, and 4) conducting experimental stockings of eggs and fry to assess their potential for re-colonizing spawning reefs.



.

Figure 2. *Numbers of lake trout (yearling equivalents) stocked into Lake Michigan by year class and strain.*

Unfortunately, full implementation of the 1985 plan was never realized. Hatchery production fell short of the recommended target of 6.2-million yearlings-per-year and only 2.4 million fish on the average were stocked annually (Figure 2). Equally alarming, intensive fisheries, especially in northern waters, resulted in mortality rates higher than the 40% target (Holey et al. 1995). Both of these factors limited the prospects for achieving the sought-after population increase of adult stocks of advanced age. Sea lamprey predation, a third factor, albeit historically modest compared to the other Great Lakes, actually increased (Lavis et al. 2003) after the plan was adopted and contributed to high total mortality. Alewife populations continued to dominate the forage base, and although reduced from historic levels, still remained unacceptably high.

Evidence for Natural Reproduction in Lake Michigan

Natural reproduction has been detected at a few locations in Lake Michigan; however, substantial natural recruitment to the adult life stage has not yet occurred. Naturally produced fry were collected from man-made rubble deposited at two locations in Grand Traverse Bay (Wagner 1981), at the Campbell Power Plant intake structure near Port Sheldon (Jude et al. 1981), and at Burns Waterway Harbor in Indiana (Marsden 1994). Viable fertilized eggs have been recovered from several locations on the east and west shorelines as well as in Traverse Bay and at Julian’s Reef (Holey et al. 1995; Marsden and Janssen 1997; Jonas et al. 2005). Wild yearlings and older lake trout of the 1976, 1981, and 1983 year-classes were caught in Grand Traverse Bay and nearby Platte Bay (Rybicki 1991).

Additionally, natural reproduction has been observed on one large offshore reef. Since the mid 1990s, large numbers of mature lake trout have been netted by the Wisconsin Department of Natural Resources during the spawning season over the extensive spawning reefs of the Mid-Lake reef complex, and spawning behavior has been observed with a remotely operated vehicle. Fertilized eggs and fry were observed (video) and collected (suction sampling) from this reef complex in 2003 and 2004 (John Janssen, University of Wisconsin-Milwaukee; personal communication). These recent observations suggest that substantial natural recruitment in Lake Michigan could come from this area, due to large numbers of spawning lake trout observed, the extensive spawning area, and its offshore location.

Why should lake trout be restored?

Several ecological and cultural reasons support lake trout restoration in Lake Michigan. First, from an ecological standpoint, lake trout, as a native species, are well adapted to life in the Great Lakes. Because of their phenotypic diversity, lake trout are capable of using the wide variety of habitats, both inshore and offshore areas, including the deepest waters of the lake. This broad use of habitat allows lake trout to use many different types of food resources (e.g., benthic and pelagic invertebrates and fishes) for growth and reproduction and eliminates their dependence on any single prey source; therefore lake trout can have a stabilizing influence on the fish community. Second, from a historical perspective, lake trout supported culturally important commercial, sport, and tribal fisheries and with restoration, can do so in the future. Even now, while in the process of rehabilitation, hatchery origin lake trout provide fishing opportunities for anglers and treaty fishers. Third, for some individuals, species such as lake trout have an important intrinsic value associated with being native and therefore warrant the efforts expended to re-establish populations. For some anglers, catching naturally reproduced wild fish is of greater value than catching a hatchery-reared fish. Lake trout restoration poses serious challenges since these fish are long lived, mature at a late age, have specific spawning requirements, and are easily over fished. Although these characteristics make restoration difficult, they make lake trout an excellent indicator of overall ecosystem health (Ryder and Edwards 1985).

Management Roles and Responsibilities

The roles and responsibilities for restoration and management of lake trout in Lake Michigan are complex and involve state, tribal, federal, and international organizations and also include decrees from federal courts. Lake trout know no jurisdictional boundaries; therefore effective management within the waters of one state requires cooperation and collaboration among all government entities that manage lake trout in Lake Michigan.

The states of Illinois, Indiana, Michigan, and Wisconsin and the Chippewa/Ottawa Resource Authority (CORA) have management authority over lake trout. Their jurisdiction and responsibility cover the lake and its watershed and much of the human population in the area, and include fishery regulation, stocking fish (other than lake trout), controlling pollution, management of physical habitat, and public education. This multijurisdictional situation is further complicated by the `U.S. District Court 2000 Consent Decree, negotiated among the Sault Ste. Marie Tribe of Chippewa Indians, Bay Mills Indian Community, Grand Traverse Band of Ottawa and Chippewa Indians, Little River Band of Ottawa Indians, Little Traverse Bay Band of Odawa Indians, the United States, the State of Michigan, and Michigan anglers (United States vs. State of Michigan 2000). The Decree specifies certain management actions related to lake trout including stocking and the control of lake trout mortality rates and exploitation. As stated in the Stipulation of Entry of 2000 Consent Decree, the eight parties to the Decree affirmed their commitment to lake trout restoration within the 1836 Treaty waters, especially the waters in northern Lake Michigan that were historically important to reproduction (Dawson et al. 1998).

The federal government through the U.S. Fish and Wildlife Service and the U.S. Geological Survey are important partners with the states and tribes in lake trout restoration. The U.S. Fish and Wildlife Service is the principal federal agency responsible for the restoration of natives species and their habitats, and has been primarily responsible for rearing and stocking most of the lake trout in Lake Michigan. The U.S. Geological Survey and the U.S. Fish and Wildlife Service provide stock assessment and research support to the restoration program.

The Great Lakes Fishery Commission, through the 1955 Convention on Great Lakes Fisheries, is responsible for management of sea lamprey, assisting with inter-jurisdictional coordination of lake trout management, and research. The Commission works with the U.S. Fish and Wildlife Service to implement an effective program of sea lamprey population assessment and control through the use of lampricides, adult barriers, adult trapping and the release of sterile males. The program seeks to minimize the damage to lake trout and other species caused by sea lamprey. The Commission also encourages inter-jurisdictional coordination of lake trout management by bringing federal, state, and tribal parties together though the Lake Michigan Committee and the Lake Michigan Technical Committee; this management plan was developed within this organizational structure. The Commission also has a long-standing history of promoting research to understand the processes associated with lake trout restoration.

Process Used to Develop the Plan

This lake trout restoration plan represents an update and revision of the earlier 1985 plan (LMLTTC). To assist in the definition of goals and objectives, a retrospective analysis of the impediments to restoration was conducted first (Bronte et al. 2003c). This analysis considered the management potential to solve well-known obstacles (i.e. sea lamprey predation) and to identify new problems (i.e. egg and fry predation by round goby) that may stand in the way of restoration. Then goals and objectives were redefined by taking into account new information, the ever-changing Lake Michigan fish community, and the important management experiences gained over the past 20 years. Management actions were then identified to address the impediments, accomplish the objectives, and achieve the goal of restoration. Studies were identified to evaluate the effectiveness of the actions in addressing the impediments and measure the progress toward restoration. These evaluations will provide critical feedback information to guide future adaptations to the management strategies as the plan is implemented.

Goal and Objectives

Goal: Reestablish genetically diverse populations of lake trout that are composed predominately of wild fish that are able to sustain fisheries.

Objective 1 (Increase genetic diversity): By 2007, and until restoration has been achieved, increase the genetic diversity of lake trout through the introduction of morphotypes adapted to deep, offshore areas while continuing to stock shallow-water morphotypes.

Objective 2 (Increase overall abundance): By 2012, achieve in refuges and high-priority areas, catch-per-effort > 25 lake trout/1000 feet of graded mesh (2.5-6.0 inch) gill net lifted during spring stock assessments (2004 lakewide CPUE arithmetic mean = 9.5 and range = 0.0-61.3). The target level of relative abundance is similar to those measured at other Great Lakes sites where natural reproduction has occurred. (Needs discussion)

Objective 3 (Increase adult abundance): By 2018, increase the abundance of adults in refuges and high-priority areas to a minimum catch-per-effort > 50 fish/1000 ft of graded large-mesh (4.0-6.0 inch) gill net fished on spawning reefs. (Needs discussion)

Objective 4 (Build spawning populations): By 2020, spawning populations in areas stocked prior to 2006 should be at least 25% females and contain 10 or more age groups older than age-7. These milestones should be achieved by 2030 in areas stocked after 2006.

Objective 5 (Detect egg deposition): By 2015, detect a minimum density of 500 viable eggs/m^2 (eggs with thiamine concentrations > 4 nmol/g) in previously stocked areas. This milestone should be achieved by 2025 in newly stocked areas.

Objective 6 (Detect recruitment of wild fish): Recruitment of wild lake trout should occur as follows: by 2020 detect age-1 fish in bottom trawls, by 2023 detect age-3 fish in spring graded-mesh-gill-net assessments, and by 2028 consistently detect sub-adults in refuges and high-priority areas.

Objective 7 (Achieve restoration): By 2035, 75% or more of the lake trout in deep- and shallow-water habitats should be age-10 and younger and of wild origin. At this time these populations will be declared rehabilitated.

Impediments to Lake Trout Restoration

The lack of achievement of the goals and objectives upon implementation of the 1985 plan indicated a need to identify and examine the factors limiting recruitment of wild lake trout. In 2000, the Lake Michigan Committee directed its Lake Trout Task Group to review the available information on lake trout biology and develop a list of potential impediments to sustained recruitment in preparation for the development of a new restoration plan. Fourteen such impediments were examined (Bronte et al. 2003c) based in part on a previous identification of research priorities for lake trout restoration in the Great Lakes (Eshenroder et al. 1999b) and based on a review of the current on-going management strategies being used. The major findings of the impediment analysis, based on Bronte et al. (2003c, with editorial changes) were used throughout the development of this plan. These impediments are the obstacles that stand in the way of achievement of the goal and objectives previously described.

Lake-wide population too low

1. Numbers stocked too low. The total number of lake trout stocked is low compared to the historical level of recruitment. Stocking numbers are inadequate to repopulate the available habitat, overcome biological and environmental impediments, and compensate for the behavioral and reproductive inefficiencies of stocked fish. Stocking should be increased as much as possible beyond the current level of 2.4 million lake trout per year.
2. Mortality too high. Losses of lake trout to sea lamprey predation and fishing need to be minimized to maximize recruitment to the parental stock and increase egg deposition. The numbers of juvenile sea lampreys need to be reduced from current levels. Management agencies must establish and maintain regulations that keep harvest at levels compatible with restoration goals.

Stocking the wrong fish in the wrong places

1. Stocking in the wrong places. Many inshore high-energy zones, inappropriate for egg incubation, are commonly used by stocked lake trout making these fish reproductively ineffective. Stocking should be focused on offshore sites. Inshore sites should only be stocked if they were historically important, have appropriate spawning habitat protected by islands or in an embayment, and can be designated for protection from exploitation. Stocking is too low in the refuges and in other offshore areas where some of the best spawning habitat exists and where fishing mortality is lowest. Stocking needs to be concentrated in areas with the best spawning habitat that are also protected from exploitation (i.e., the refuges).

2. Limited genetic diversity. The genetic diversity of stocked fish has been limited compared to what was present historically. This deficiency inhibited re-colonization of inshore and offshore habitats and the reestablishment of historical predator-prey relationships in deep water. The genetic diversity within and among lake trout forms should be increased to encourage re-colonization of deep water and offshore habitats, and to reduce mortality from fishing and sea lamprey predation.

3. Only yearlings stocked. The stocking program has relied almost solely on yearling fish, thus the potential of other life-history stages was never fully investigated. The stocking of eggs and fry over or adjacent to optimal spawning habitat should be increased, first as pilot studies, to determine whether these life stages offer improved performance over yearlings, and if so, under what conditions.

Poor survival of early-life stages

1. Disease. Consumption of alewives, a non-native fish, by adult lake trout causes early mortality syndrome (EMS) in their progeny, hence increased predation and/or fishing pressure on alewives is needed to suppress their numbers forcing lake trout to diversify their diets. Restoration of native coregonines should be encouraged as this may alleviate recruitment problems from EMS.
2. Predation. Predation by native and non-native species on lake trout eggs and fry reduces potential recruitment; hence stocking should be concentrated to achieve densities of adults and eggs that can overcome these mortality bottlenecks. Densities of benthic egg/fry predators are likely lower offshore so stocking should be a priority there. Stocking densities should emulate or exceed historical densities of wild fish.
3. Lack of predation on egg and fry predators. Lake trout need to become more of a dominant predator in the fish community in areas targeted for restoration. This will allow them to suppress native and non-native egg and fry predators, thereby decreasing recruitment losses. Such dominance is important, especially in those regions where spawning habitat is aggregated.

Special Concern for Early Mortality Syndrome as an Impediment

Early Mortality Syndrome (EMS) may be the most difficult impediment to overcome. EMS occurs when lake trout eggs are deficient in thiamine and causes direct mortality during hatching and indirect mortality afterward. Clinical signs of EMS include loss of equilibrium, swimming in a spiral or corkscrew pattern, lethargy, dark pigmentation, hyper-excitability when touched, and failure to feed (Marcquenski and Brown 1997). The presence of thiaminase, an enzyme that destroys thiamine, in alewives consumed by adult lake trout has been determined to be the cause of EMS (Honeyfield et al. 2005). Thiaminase-producing algae or bacteria are suspected to be the source of thiaminase in the food chain. Zooplankton consume thiaminase-producing algae or bacteria, and are then eaten by alewives which act as vectors for thiaminase to lake trout. Annual and spatial variations in the prevalence of EMS in lake trout and Pacific salmon may be the result of ecosystem changes that favor elevated thiaminase activity in algae or bacteria leading to increased concentrations of thiaminase in alewife.

Even though the role that thiaminase plays in EMS is not completely understood, research on lake trout captured from the wild or reared under controlled laboratory experiments has clearly shown that when alewife are prominent in the diet, EMS occurs and reproductive potential is impaired (Fitzsimons and Brown 1998). A threshold thiamine concentration of 1.5 nmol/g or less causes direct mortality on lake trout fry (Brown et al. 1998; Honeyfield et al. 2005). Indirect mortality in affected fry with thiamine levels below 4.0 nmol/g has also been observed (Brown and Honeyfield 2004). This can be caused by impaired vision, reduced ability to avoid predators, susceptibility to bacterial pathogens, slower swimming speed, and slower growth. Total amelioration from EMS may not occur until egg thiamine levels are much higher than 4 nmol/g. Of 191 ripe females sampled from Lake Michigan during 1996-2003, the mean egg thiamine concentration was 3.38 nmol/g and 76% were below 4.0 nmol/g (Dale Honeyfield, U.S. Geological Survey, Wellsboro, PA; personal communication). Strategies that reduce the occurrence of alewife in the diet of Lake Michigan lake trout or decrease the availability of thiaminase to alewife need to be developed or poor survival of lake trout fry will continue to hinder the restoration effort in Lake Michigan.

Management Actions

Stocking

ACTION: Stock only in high priority areas having high-quality spawning habitat and protection from fishing.

RATIONALE:

Priority areas. Stocking will be focused in areas where spawning reefs are aggregated or protected from high-energy events, and where the protection from excessive fishing mortality is expected. Areas of the lake identified for stocking comprise three separate regions that differ in habitat quality and protection from fishing. Historical commercial-fishing records (Dawson et al. 1997) and more-recent evaluations of stocking practices (Bronte et al. 2003a) and habitat (Marsden et al. (in review)) were used to prioritize regions where prospects for lake trout reproduction are highest. Most of the lake trout spawning habitat is located offshore within and around the Northern Refuge and within the Mid-Lake Refuge (Figure 1).

First Priority: These areas have the highest likelihood of supporting self-sustaining populations. They are located predominately offshore, have the greatest protection from excessive fishing mortality, have the largest area of quality habitat and historically supported the largest aggregations of native spawning lake trout.

1) Shallow-water reefs in Statistical District MM-3, including the Northern Refuge. Specific reefs are grouped based on location and adjacency to neighboring reefs as follows (Figure 3):

West Beaver Group – High Island, Boulder Reef, Trout Island, and Gull Island Shoal.

East Beaver Group – Dahlia Shoal, Hog Island Reef, and Ile aux Galets, Charlevoix Group – Big Reef, Fisherman Island, Irishmen's Ground, and Middle Ground.

2) Deepwater reefs in the Mid-Lake Reef Refuge and in Illinois, specifically Milwaukee Reef, East Reef, Northeast Reef, Sheboygan Reef, and Julian's Reef.

3) Deepwater habitat, greater than 50 m, on either side of the Fox Islands.

Inner Fox Trench – on the east side between the Fox Islands and the main land.

Outer Fox Trench - on the western side of the Fox Islands toward the open lake.

Second Priority: These areas have high likelihoods of harboring self-sustaining populations are predominately nearshore (some protected by embayments), and historically possessed significant spawning aggregations of native fish, but where fishing regulations may not be as stringent as in First Priority areas. Specific spawning sites are listed by statistical district:

MM-2 – Point aux Barques Reef, Point Detour, and Portage Bay Reef

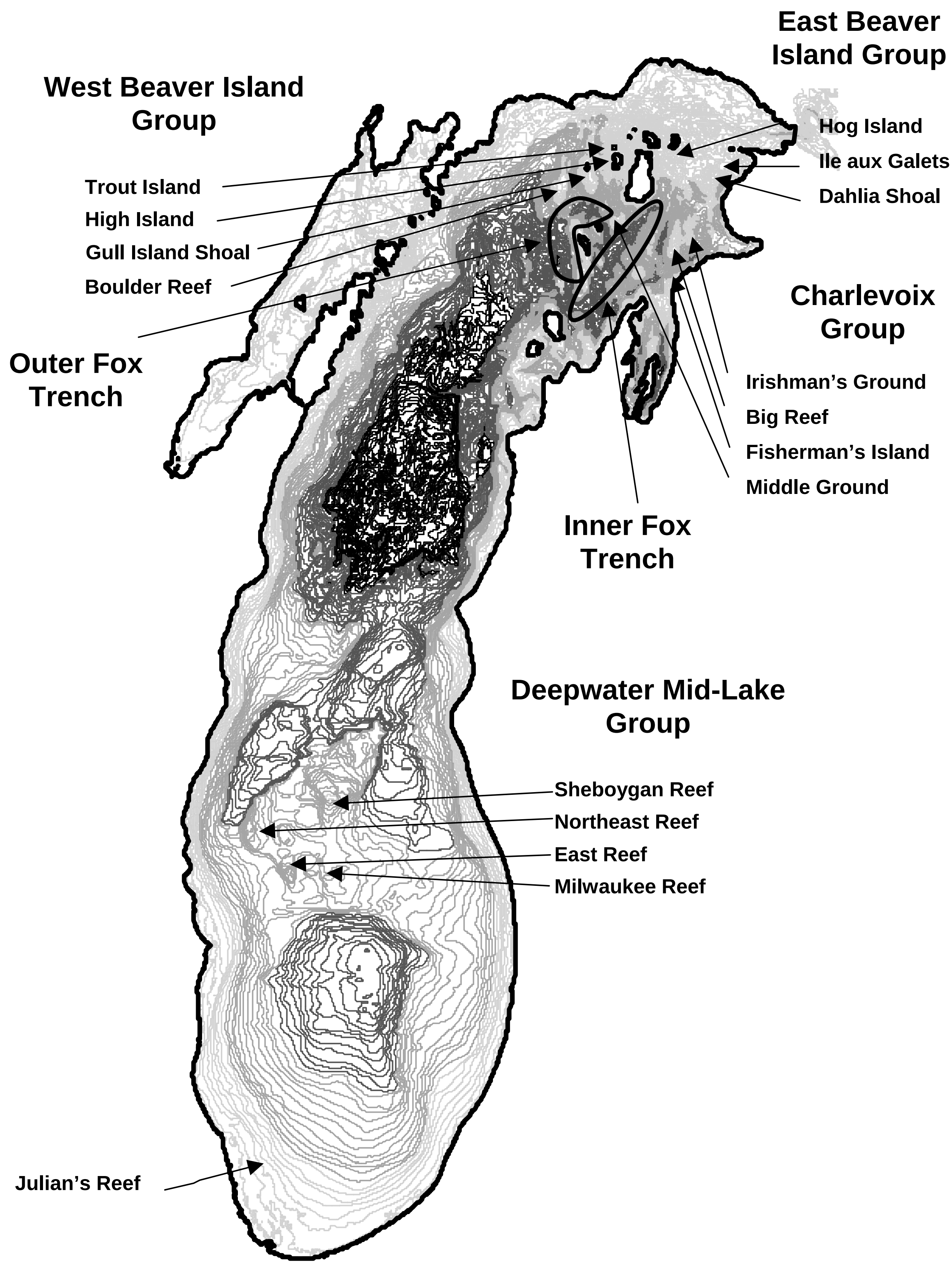
MM-3 – Fisherman's Island

MM-4 – Cherry Home, Ingalls Point, Old Mission Point, and Lee Point.

MM-5 – Good Harbor Bay, Cat Head Point and Reef, North Reef, North Manitou Island, South Manitou Island, North Manitou Shoals

WM-3 – Cardy's Reef, Whitefish Bay, Cana Island, North Bay, and Four Foot Shoal.

Figure 3. *First priority spawning reefs and regions discussed in plan*.



Third Priority: All remaining areas of Lake Michigan are in this group and are considered to have a lower likelihood of self-sustaining populations. These areas have sparse spawning habitat and historically did not have significant aggregations of spawning lake trout. Third Priority areas will not receive yearling fish because of limited hatchery production but may receive fall fingerlings depending on their availability. If stocking should occur, specific sites and numbers would have to be identified by the Lake Trout Task Group.

Impediments Addressed: *Stocking numbers too low, Stocking in wrong places*.
Objectives Addressed: *Increase overall abundance*, *Build spawning populations.*

<u>Genetic Origins of Stocked Lake Trout</u>

ACTION: Stock the strains listed below in equal proportions by life stage and number within each habitat type in First Priority Areas.

Shallow-Water Habitats (0-50-m depth; 25% of each)

- Apostle Islands Wild (SAW; Lake Superior origin)
- Lewis Lake (LLW; Lake Michigan origin)
- Seneca Lake (SLW; Lake Ontario drainage)
- Parry Sound (Lake Huron origin – brood stock under development; first year class available in 2013)

Deep Water Habitats (> 50m depth; 50% of each)

- Seneca Lake (SLW; Lake Ontario drainage)
- Klondike Reef Strain (SKW; Lake Superior origin)
- Siscowet (Lake Superior origin - Future)

RATIONALE: This action addresses the impediment that genetic and phenotypic diversity of previously stocked lake trout was limited and did not represent historical levels. Page et al. (2004) has shown that an important component of genetic diversity among wild populations in Lake Superior was organized by morphotype (lean, humper, and siscowet). These morphotypes use different habitats (e.g., shallow water, deep water, steep banks) and food sources (Larwie and Rahar 1971; Conner et al. 1993; Krueger and Ihssen 1995; Moore and Bronte 2001; Harvey et al. 2003). The choice of strains was based on matching the native habitats of donor sources to the deep and shallow-water habitats of Lake Michigan. The criterion for choosing appropriate strains is similar to the 1985 plan (Krueger et al. 1983; LMLTTC 1985) but here is implemented with a different suite of strains. Strains chosen also reflect the greater diversity among morphotypes (lean and humper) and among lake basins (e.g., Lake Superior, Lake Huron, Seneca Lake) than in the earlier plan. Lake Superior lean strains stocked under the previous plan (Marquette, Apostle Island, Isle Royale, Traverse Island) were ecologically and genetically redundant hence we chose only the Apostle Island strain since they appear to be more genetically diverse than the Marquette strain and have better post- release survival than the Isle Royale strain in Lake Michigan (Bronte 2003a).

Strains are selected from locally adapted stocks from the Great Lakes basin that are capable of inhabiting both shallow (<50m) and deep water (> 50 m). These strains are progeny from populations that successfully reproduce in other Great Lakes, in inland lakes in the basin (Seneca Lake), or in lakes where Lake Michigan stocks were transferred (Lewis Lake, Wyoming). This strategy assumes that the genetic traits required for survival and reproduction are present in the hatchery stocks and will be expressed after stocking into Lake Michigan. This approach, the introduction of genotypes of geographically proximate populations, is comparable to similar strategies suggested for restoration of Pacific salmon and other species (Krueger et al. 1981; Miller and Kapuscinsiki 2003; Reisenbichler et al. 2003).

Selecting strains based on habitat preferences infers that if restoration is to occur in both deep and shallow waters, different types of lake trout need to be stocked. Historically, different forms of lake trout lived in Lake Michigan (Brown et al. 1981). Many different shallow water forms were recognized by commercial fishermen and were found on the various shallow water reefs in northern Lake Michigan. Deepwater forms of lake trout were known in fisheries adjacent to the Beaver – Manitou Island region of northern Lake Michigan. Smith and Snell (1891) stated that the "siscowet or deepwater variety of the trout" occurred "throughout the northern portion of the lake … especially between the Manitou and Beaver Islands. In some places fully half the trout taken are of this kind." Shallow- and deep-water forms were also reported to occur on both sides of the northern (Grand Traverse Bay and in the vicinity of Two Rivers, Wisconsin) and the southern portion of the lake (Goode 1884), and in Illinois waters (Coberly and Horrall 1982) Based on interviews of commercial fishermen who fished during 1920-1950 (cited in Brown et al. 1981), deep-water lake trout spawned on the Sheboygan, Northeast, East, and Milwaukee reefs over clay, gravel, and limestone outcroppings at depths of 55-79 m.

The choice of shallow-water strains was based on knowledge of their survival after stocking in Lake Michigan and elsewhere in the Great Lakes. Recently, a comparison of survival after stocking at spawning sites in Lake Michigan indicated that Lewis Lake, Apostle Islands, and Seneca Lake wild strains survived better than the Green Lake, and Superior Isle Royale strains (Bronte et al. 2003a). Based on the results of this study, the space constraints in federal hatcheries to hold multiple strains, and the rationale described above, the former three strains should be stocked into shallow water habitats in Lake Michigan. The Marquette strain from Lake Superior had similar post release survival as the Lewis Lake and Seneca Lake strains but is being replaced by the Apostle Islands strain.

The Seneca strain is recommended for stocking into both shallow- and deep-water habitats. Royce (1951) reported that the lake trout in Seneca Lake spawn in water greater than 50 m in late September and early October. Although upon introduction this strain has been documented to spawn in shallow water in the Great Lakes, the Seneca strain lake trout should have the genetic capability to successfully occupy deep-water habitats in the Great Lakes. The Seneca strain has survived consistently well in other Great Lakes and has produced detectable recruitment when compared to other strains in the Great Lakes (e.g., Grewe et al. 1994; Perkins et al. 1995; Page et al. 2003; R. Philips, Washington State University, Vancouver, WA; personal communication).

In addition to the Seneca strain, deep-water habitats should be stocked with the Klondike strain. This strain is recommended for stocking deep-water habitats because of the ecological similarity between deep offshore reefs in Lake Superior and the Mid-Lake reef complex in Lake Michigan. Klondike Reef is located about 57 km northeast of Grand Marais, MI in the Michigan waters of Lake Superior and is an underwater hill that ranges from 40 to 60 m deep on top, and from 90 to 250 m deep on the bottom. The Klondike broodstock were developed from humpers, a distinct form of lake trout from deep waters of Lake Superior that should be ideal for stocking the deep waters of Lake Michigan.

One new source of shallow-water lean lake trout, the Parry Sound strain, which is now being developed, should be introduced into Lake Michigan. This strain is from a remnant population in Lake Huron that has rebounded since the mid-1980s (Reid et al. 2001). This population increased to more than 10,000 individuals after fishing and sea lamprey mortality were controlled. Parry Sound has a maximum depth of 112 m and an average depth of 41m therefore, these fish should be ideal for restoring populations in shallow-water habitats of Lake Michigan.

Another source to consider for future introduction is the deep-water siscowet lake trout, which is an important component of the Lake Superior populations (Bronte et al. 2003b). Siscowet are found typically in water deeper than 75 m (Moore and Bronte 2001; Bronte et al. 2003b) and appear to have multiple stocks that spawn at various times of the year (Bronte 1993). This form of lake trout should be ideal for recolonizing the large amount of habitat formerly used by native deep-water lake trout in Lake Michigan (described above) because of its consistent use of deep offshore waters, resistance to the effects of sea lamprey mortality in Lake Superior, and potential to use a variety of habitats. An abundance of deep-water lake trout may promote re-establishment of shallow-water lake trout populations by suppressing through predation species such as burbot (*Lota lota*) (Bronte et al. 2003b), who are thought by some to compete and/or prey on lake trout young (see Ward et al. 2000).

Impediments addressed: *Limited genetic diversity.*

Objectives addressed: *Increase genetic diversity.*

<u>Life Stages to be Stocked</u>

ACTION: Stock a variety of life stages (fry, fingerlings, and yearlings) to increase the potential for imprinting, thereby increasing the likelihood that these fish at maturity will aggregate on the highest quality spawning habitat and decrease the time for restoration.

RATIONALE: Life stages that are readily available for stocking are: 1) eggs or sac fry (pre-imprinting), 2) fingerlings (post-imprinting), and 3) yearlings (post-imprinting). Yearlings have been, and will remain the cornerstone of the stocking program in the

Great Lakes. Stocking this life stage has the highest post-release survival and has contributed to the restoration of near-shore areas of Lake Superior and partial restoration in Lakes Ontario and Huron (Hansen 1999). Stocking fertilized eggs, fry, and fingerlings has not been as widely implemented and the results from egg stocking have been mixed (Bronte et al. 2002; USFWS, New Franken, WI, unpublished data; MIDNR, Charlevoix, MI, unpublished data). Stocking early-life stages onto reefs will likely enhance the potential for imprinting and may result in greater densities of adults on spawning reefs (especially those offshore) than those achieved from stocking yearlings alone. This plan advocates an increased use and evaluation of early-life stage stocking to enhance the colonization of spawning habitats.

Fry (Experimental) – Fry (3-4 months old) stocking should be considered where return rates from yearlings were poor yet habitat and other factors indicate favorable conditions for reproduction. The goal is to place fry on optimal habitat to maximize their potential to imprint and return to spawn. Because this technique has not been adequately tested, an experimental approached is recommended at this time and discussed below.

Fingerlings – Fingerlings (10-12 months old) should be stocked in Second- and Third-priority areas over habitats where their prospects for survival and reproduction are highest. This life stage probably will not do well in First-priority areas where predation from existing populations of adult lake trout may impede their survival. Fingerlings survival appears to the highest when the receiving location is devoid of lake trout.

Yearlings - Yearling lake trout (15-18 months old) will remain the primary life stage for reintroduction and will be stocked in First-priority areas. Their larger size results in better post-release survival and this life stage is most likely to build adult densities required for reproduction. As more yearlings become available, they can be stocked into Second- and Third-priority areas once the needs for First-priority areas are met.

Adults (Experimental) - Adult transfers from Lake Superior were recommended in the 1985 Plan but were never implemented. This technique has had much success in bird and mammal re-introductions world-wide and has been successful for fish introductions in small lakes. Experimental transplants of wild, adult lake trout should be made onto a small, isolated reef surrounded by deep water that can be readily assessed for egg deposition and fry emergence.

Impediment addressed: *Only yearlings stocked*.
Objectives addressed: *Increase overall abundance, Increase overall abundance, Build spawning stocks.*

Criteria for Hatchery Rearing

ACTION: Stock high quality fish that are as genetically diverse as the donor stock used to create the captive broodstock.

RATIONALE: Hatchery rearing methods and conditions can affect the quality and survival of stocked fish. The Goede's fish health index (Goede 1991) has been the standard to evaluate the quality of hatchery-reared fish. Studies at federal hatcheries in the Great Lakes indicate that factors such as fat index, percentage of abnormal eyes and fins, and condition (K_{TL}) are significantly improved by rearing protocols that focus on fish quality rather than size. Because of these results, target criteria for selected quality measures have been developed and adopted for the federal lake trout hatcheries that provide fish for Lakes Michigan and Huron (Table 1). Similar quality criteria are recommended for all hatcheries, including tribal and state facilities, that supply lake trout to Lake Michigan, and should be further evaluated and improved.

Table 1. *Quality targets established by the National Fish Hatchery System for lake trout stocked into the upper Great Lakes (based on Goede 1991).*

Metric	Target
Visceral fat	85% classified with a fat index of 2.0 or greater; 0% classified with a fat index of 0.0
Eyes	≥90% classified as normal
Gills	≥90% classified as normal
Fins	≥85% classified as normal

Broodstocks and their progeny should be propagated so as to minimize the loss of genetic variation. The objectives over three generations are to lose < 1% of the genetic variability and to have a 95% chance of possessing an allele that occurs at 1% in the donor stock. More details regarding genetic guidelines for the establishment of broodstocks and the propagation of fish for stocking are provided by Page (2001), Miller and Kapuscinski (2003), Reisenbichler et al. (2003), and Holey (2000).

Impediment addressed: *Mortality too high, Limited genetic diversity.*

Objectives addressed: *Increase overall abundance.*

<u>Numbers or densities to be stocked</u>

ACTIONS:

- Stock yearling lake trout at a density of 4.5 fish/hectare.

- Stock 3.6 million yearling lake trout in First-priority areas as specified in Tables 2 and 3. The National Fish Hatchery system has been the primary source of lake trout for the upper Great Lakes and is currently capable of producing 3.5 million yearlings each year of which 2.4 million are reserved for Lake Michigan. With facility improvements, production is expected be about 5.1 million fish, of which 3.4 million fish would be available to Lake Michigan.
- (Experimental) Stock sac fry of the Seneca strain at a density of $500/m^2$ at Hog Island and Dahlia Shoal, and/or Omena Point for six consecutive years. Densities are based on estimates of the number of eggs/meter ^{2} needed to survive about 4-weeks of predation in Lake Michigan prior to winter to insure adequate fry numbers in spring (Jonas et al. 2005). Fry are relatively easy to produce and require little hatchery space. Hatch dates would need to be delayed until mid-April to facilitate deployment.
- Stock fall fingerlings as available in Second- and Third-priority areas. Fall fingerlings are often available as surplus in the hatchery system as fish grow and rearing capacities become taxed.

RATIONALE: Over the past decade, knowledge has improved about the required density of stocked lake trout and the location of high priority areas to focus management efforts. This improved understanding was based on analysis of historical data (e.g., Holey et al. 1995; Dawson et al. 1997) and the potential impediments to restoration (Bronte et al. 2003c). Consistent with this information and analysis, the 2000 Consent Decree directs the Tribes, the State of Michigan, and the United States to increase stocking as soon as possible in Statistical Districts MM-1, MM-2, MM-3, MM-4, and MM-5 (Figure 1) to a level comparable to lake trout restoration goals which amounts to about

1.7 million yearlings annually in northern Lake Michigan. Increased stocking densities should also intensify predation on alewives and add to suppression.

Impediments addressed: *Numbers stocked too low, Only yearlings stocked, Disease, Predation, Lack of predation on egg and fry predators.*

Objectives addressed: *Increase overall abundance*, *Increase adult abundance.*

<u>Timing and Methods of Distribution</u>

ACTIONS:

Yearlings

- Stock yearling lake trout as early as practical in spring, at least by late June.
- Stock yearlings by boat at a minimum depth of 30 m adjacent to designated spawning sites (see above) and distribute fish evenly so as to avoid creating aggregations attractive to predators.
- Yearlings with coded wire tags (CWT) will be planted experimentally at four designated spawning sites as near to the sites as is practical. The survival of these fish will be compared to that of CWT fish released at minimum depths of 30 m in close proximity to the reef to test the effects of depth of water on survival and their rate of return as adults.

RATIONALE: Releasing an entire tank load of fish all at once may increase their vulnerability to predation by attracting predators. Spreading fish over a wider area is expected to lower predatory losses as has been hypothesized for Lake Huron where survival increased for year-classes that were spread out when stocked by boat (Johnson et al. 2004).

The ability of yearling lake trout to imprint to a stocking site has been questioned. In Lake Michigan, stocked reefs develop significantly larger spawning aggregations than those that were not stocked (Bronte et al. 2003a). Ninety percent of CWT fish recovered during spawning were captured within a range 24-146 km from where they were stocked. Though stocking directly on reefs appears to be effective, homing back to the site of release is moderate at best as was observed in Lake Ontario (Elrod et al. 1995); this weak tendency could be lost entirely if fish are stocked too far from spawning reefs. Survival of yearlings may be enhanced if released over deeper water (Johnson et al. 2004), which is the preferred habitat by age-1 lake trout in spring (Eschmeyer 1956; Van Oosten and Eschmeyer 1956; Selgeby and Hoff 1996) as opposed to shallower depths on spawning reefs.

Sac fry (Experimental)

- Stock sac fry as soon as possible after ice-out on reefs designated above.
- Stock sac fry directly over identified high-quality spawning habitat at densities of approximating 500/m^2.

RATIONALE: Stocking of sac fry avoids the problems of domestication effects associated with hatchery rearing and should enhance imprinting and subsequent return as adults. Predation on sac fry will be lessened if they can immediately find space within spawning substrates. Methods for planting sac fry need to be researched to improve efficacy.

Impediment addressed: *Numbers stocked too low*, Only *yearlings stocked, Predation*.

Objectives addressed: *Increase overall abundance.*

Adults (Experimental)

- Capture and transport 500 lake trout spawners/year for three consecutive years from Michigan waters of Lake Superior and transport them to an isolated but accessible offshore reef devoid of lake trout. All fish would be tagged prior to introduction into Lake Michigan and their subsequent use of the reef and any egg deposition would be monitored for five years.

RATIONALE: This approach addresses several challenges associated with lake trout restoration. Restoration takes a long time in part because lake trout require five or more years to attain maturity. The proposed approach will accelerate this process by as much as five to seven years because the stocked fish are already mature. Natural seeding of the reef with eggs from transferred adults would occur immediately and these eggs would have the rearing advantages associated with natural substrates (e.g., fry imprinting). If adult transfers are successful, populations could become established rapidly as has been predicted for other reintroduction programs (Sarrazin and Legendre 2000). Additionally, stocked lake trout may suffer from domestication effects (Reisenbichler et al. 2003) because they have been raised in a hatchery for up to 1.5 years and are the products of hatchery broodstocks. Transplantation of wild adults avoids the problem of reduced fitness in the wild caused by domestication because this approach does not require hatcheries.

<u>Distribution of Stocked Fish</u>

The strategy described below recommends stocking deep- and shallow-water lake trout within selected areas of Lake Michigan. This approach should result in larger parental stocks than those developed from the implementation of the 1985 Plan. The numbers and strains, and their distribution by deep and shallow-water habitat type for the selected areas surrounding and including the Northern Island and Mid-Lake Reef refuges, and in southwestern Lake Michigan are given in Tables 2 and 3.

Table 2. *Stocking levels and distribution of yearling lake trout in northern Lake Michigan by geographic area (see Figure 3), strain, and release site. Strains to be stocked are Klondike Reef (SKW), Seneca Lake (SLW), Lewis Lake (LLW) and Apostle Islands (SAW).*

		Number by strain			
Geographic Area	**Habitat targeted**	**LLW**	**SLW**	**SAW**	**SKW**
West Beaver Group	Shallow water, on reef	80,000	80,000	80,000	
	Shallow water, off reef	80,000	80,000	80,000	
East Beaver Group	Shallow water, on reef	80,000	80,000	80,000	
	Shallow water, off reef	80,000	80,000	80,000	
Charlevoix Group	Shallow water, on reef	40,000	40,000	40,000	
	Shallow water, off reef	40,000	40,000	40,000	
Outer Fox Trench	Deep water		200,000		200,000
Inner Fox Trench	Deep water		200,000		200,000
Total by strain		400,000	800,000	400,000	400,000

At the Mid-Lake Reef Refuge and Julian's Reef, Klondike (SKW), and Seneca Lake Wild (SLW) lake trout will be stocked in equal numbers on (over the apex) and adjacent to (45 m) the four principal reefs (Table 3). Stocking will be deferred at East Reef for five years from the implementation of this plan because this site already has high densities of lake trout.

Table 3. *Stocking levels and distribution of yearling lake trout in the Mid-Lake Reef Refuge and Julian's Reef by strain and release site. Strains to be stocked are Klondike Reef (SKW) and Seneca Lake (SLW).*

Geographic Area	Habitat targeted	Number stocked by strain and habitat	
		SKW	**SLW**
East Reef	Over reef summit	100,000	100,000
(after 5 years)	Off to side	100,000	100,000
Northeast Reef	Over reef summit	100,000	100,000
	Off to west side	100,000	100,000
Sheboygan Reef	Over reef summit	100,000	100,000
	Off to northeast side	100,000	100,000
Milwaukee Reef	Over reef summit	100,000	100,000
	Off to south side	100,000	100,000
Julian's Reef	Over reef summit		60,000
	Off to side	60,000	
Total by strain		860,000	860,000

Impediment addressed: *Numbers stocked too low*, *Stocking in the wrong places.*.

Objectives addressed: *Increase overall abundance, Increase adult abundance, Build spawning populations.*

Adaptive Approach to Stocking

To insure the judicious use of the limited hatchery production, the performance and survival of hatchery-reared fish should be re-evaluated every three years to allow for timely adjustments to the stocking strategy. Adjustments to stocking will be based on the following:

1. Reductions in the number of fish available for stocking due to production problems in hatcheries will result in proportional reductions across First-priority areas. Maintaining the integrity of any study designs will be a high priority when such reductions occur.
2. In areas with total annual mortality (A) greater than 40% for five consecutive years, the management agencies, working with control agents of the Great Lakes Fishery Commission, must develop a targeted plan to reduce mortality. Total mortality should be separated into its natural, fishing, and sea lamprey components to identify the appropriate management action(s) needed to reduce losses. If mortality targets cannot be met, stocking will be reduced or terminated, and fish will be reallocated to areas where survival is better.
3. Stocking will be reduced or terminated near designated spawning sites when the CPUE of adults in fall is poor in relation to expectations. Fish designated for these areas should be reallocated to areas where colonization by adults is occurring or to new areas contiguous with those already being stocked. At sites where excessive mortality does not explain the poor adult CPUEs, early- life stages should be deployed as an alternative to yearlings.
4. For previously stocked areas, stocking will be reduced or terminated in areas where unacceptable density dependent declines in survival occur (when R/S is 25% of highest level).

5. Stocking will be terminated on reefs where natural recruitment is increasing and sustainable.

Impediments addressed: *Mortality too high, Stocking in wrong places.*

Objectives addressed: *Increase overall abundance*, *Increase adult abundance, Build spawning populations.*

Diversification of Lake Trout Diet

ACTION: Investigate a strategy to restore or enhance lake herring and deepwater coregonines in Lake Michigan for the purpose of lowering the prominence of alewife in lake trout diet which will reduce the prevalence of EMS in lake trout fry.

RATIONAL: Natural reproduction of lake trout is most successful in those areas of the Great Lakes (Lake Superior and parts of Lake Huron) harboring healthy populations of native coregonines and exhibiting low incidence of EMS in lake trout fry. Strategies to restore or enhance lake herring (*Coregonus artedii*) and kiyi (*Coregonus kiyi*) in Lake Michigan are consistent with efforts to reduce thiamine deficiencies by providing alternative prey for top predators. Further suppression of alewife populations may diminish the socioeconomically important sport fishery for Pacific salmon; however this decline may not be severe. Coregonines made up 19% by weight of the diet of Chinook salmon in Lake Superior during 1981-1987 (Conner et al. 1993) indicating that salmon will feed and grow well on a diet of coregonines. In addition, stocking strains of lake trout that live in deeper offshore waters (Klondike) or deeper in the water column (i.e. Seneca Lake strain, Royce 1951, Bergstedt et al. 2003), and are more likely to encounter alternate prey like bloater (*Coregonus hoyi*), which may decrease the impacts of EMS on lake trout.

Impediments Addressed: *EMS/Disease, Predation.*

Objective Addressed: *Increase overall abundance, Detect recruitment of wild fish*

Regulations

Stocked lake trout and their progeny will need to be protected from over-fishing if the goal and objectives of this plan are to be realized. Healey (1978) suggested that to sustain wild lake trout populations, the maximum total annual mortality should not exceed 50% for populations with natural mortality rates of 20-30%. Lake trout, which are long-lived, late to mature, and have low fecundity, are likely to decrease in abundance when fishing mortality exceeds 15%. To achieve restoration, conditions must exist to allow for both population sustainability and expansion. Thus, restoration requires that total mortality (hence fishing and sea lamprey) must be low to allow adequate escapement and rebuilding of adequate parental stocks. To achieve these conditions, restoration plans for Lake Superior (45%, Hansen 1996) and the1985 Plan for Lake Michigan (40%, LMLTTC 1985) adopted ceilings lower than 50% on total mortality. It is recommended for this plan that total mortality should not exceed 40% for the mature lake trout in Lake Michigan. Recent estimates (2003) of total mortality and its constituent parts, based on statistical catch-at-age models, for the 1986-Treaty waters of Lake Michigan are given in Table 4.

Table 4. *Estimates of total, natural, fishing, and sea lamprey-induced annual mortality for lake trout for selected statistical districts in Lake Michigan in 2003 (Modeling Subcommittee, Technical Fisheries Committee 2004; unpublished data).*

	2003 Average annual mortality			
	Total	**Natural**	**Fishing**	**Sea lamprey**
Statistical District	**(A)**	**(v)**	**(u_F)**	**(u_L)**
MM-1,2,3 combined	0.44	0.21	0.10	0.21
MM-4	0.49	0.25	0.14	0.22
MM-5	0.40	0.27	0.07	0.12
MM-6,7 combined	0.27	0.18	0.06	0.06

These estimates indicated that natural mortality ranges from 18 to 27%, while mortality from sea lamprey predation now ranges from 6 to 22%. These results also suggest that fishing mortality must remain low and that sea lamprey mortality must be reduced significantly if target mortalities are to be reached and maintained. Since 2001 significant decreases in fishing mortality have resulted through the coordinated management efforts stipulated in the 2000 Consent Decree and the resolve of the parties. For a population under restoration, no surplus production logically exists to support fisheries (Krueger and Ebener 2004) or other sources of mortality, thus, every effort should be made to maintain low fishing mortality and significantly reduce sea lamprey populations. The Great Lakes Fishery Commission must maintain an increased control effort on Lake Michigan if lake trout population increases are to occur.

<u>Best Harvest Practices</u>

ACTION: Establish regulations that will protect mature (age 7+) from exploitation.

RATIONALE: All harvested lake trout are not equal. Mature (age 7+) lake trout should be protected more than immature fish as they can contribute immediately to reproduction. Further, older fish (larger) fish are more fecund than fish that have just matured (O'Gorman et al. 1998). Lake trout populations are better able to withstand a nominal harvest of younger fish, which are more abundant and reproductively less valuable. When possible, harvest efforts should be directed away from large and old fish. Slot-size limits, which permit harvest of immature fish and minimize harvest of adult fish, should be encouraged and implemented lake wide for recreational fisheries.

Impediments addressed: *Mortality too high.*

Objectives addressed: *Increase overall abundance*, *Increase adult abundance, Build spawning populations.*

<u>Selective Fisheries</u>

ACTION: All unmarked lake trout (those without fin-clips) should be immediately returned unharmed to minimize fishing mortality on wild fish.

RATIONALE: The absence of fin clips on recaptured lake trout may indicate that these fish were naturally produced. Though unclipped fish may be those missed during marking in the hatcheries (marking efficiencies are about 95%), all lake trout with intact fins should be considered wild recruits and released alive when captured in sport and commercial fisheries. Reducing fishing mortality further on these fish, which presumably survived the impediment bottlenecks, increases the chance of passing the genetic and behavioral traits responsible for their survival to the next generation. This strategy is being widely used in efforts to conserve and enhance wild salmon populations along the West coast of North America and steelhead (*Oncorhynchus mykiss*) in Lake Superior.

Impediments addressed: *Mortality too high.*

Objectives addressed: *Increase overall abundance*, *Increase adult abundance, Build spawning populations.*

Development of biologically compatible harvest regulations

ACTION: Implement regulations consistent with mortality and abundance estimates from statistical catch-at-age analysis (SCAA) models.

RATIONALE: Political and social realities require some level of harvest concurrent with this restoration effort. Appropriate levels of fishing need to be compatible with the spirit of restoration, and be estimated from the available data. Survey data, along with information on harvest and other losses, need to be scaled up to a population level to allow for examination of population trajectories. SCAA models partition mortality among commercial and recreational fisheries, sea lamprey, and natural sources and describe how these losses have changed over time. Statistical catch-at-age analysis is widely viewed as a state-of–the-art assessment approach (e.g., Fournier and Archibald 1982; Hilborn and Walters 1992; Methot 1990, 2000; NRC 1998; Quinn and Deriso 1999) and is currently employed to manage lake whitefish (*Coregonus clupeaformis*) and lake trout fisheries in 1836 Treaty waters in Lakes Superior, Huron and Michigan (Modeling Subcommittee, Technical Fisheries Committee 2004) and lake trout fisheries in the Wisconsin and Minnesota waters of Lake Superior. Model development for all waters of Lake Michigan is needed to evaluate the progress toward achieving restoration objectives and to make more-informed decisions on allowable harvest.

Impediments addressed: *Mortality too high.*

Objectives addressed: *Increase overall abundance*, *Increase adult abundance, Build spawning populations.*

Sea Lamprey Control

ACTION: Limit sea lamprey populations to no more than 58,000 $\pm$ 13,000 adults, a level commensurate with a marking rate of 4.7 marks per 100 lake trout.

RATIONALE: Suppression of sea lampreys has contributed to improved survival of lake trout and other salmonines in Lake Michigan. However, significant increases in the sea lamprey population over the past two decades have occurred (Lavis et al. 2003) and numbers have tripled since 2000. Currently, sea lamprey kill far more lake trout than all fisheries combined and is now a considered a major impediment to lake trout restoration. The Lake Michigan Committee defined a general objective for sea lamprey calling for suppression to achieve their Fish Community Objectives (Eshenroder et al. 1999a) including lake trout restoration. The target abundance of sea lampreys that would achieve the Objectives is estimated to be 58,000 (+/- 13,000), and is based on estimates of wounding rates, subsequent mortality on lake trout and the abundance of sea lampreys. Sea lamprey abundance has been above this target during the recent past as observed in assessments of spawning adults (Figure 4). The Great Lakes Fishery Commission and its agents increased control during 2001-2004 that included treatments of new lentic areas and the large previously untreated Manistique River, which contained millions of larvae. Increased control is expected to achieve the sea lamprey target and should result in a decrease in marking (Type- A 1-3) on lake trout. Marking rates have been continually increasing above the 5 marks per 100 fish target since the mid 1990s (Figure 5). Lakewide control efforts need to be increased to reduce sea lamprey numbers to at or below target levels.

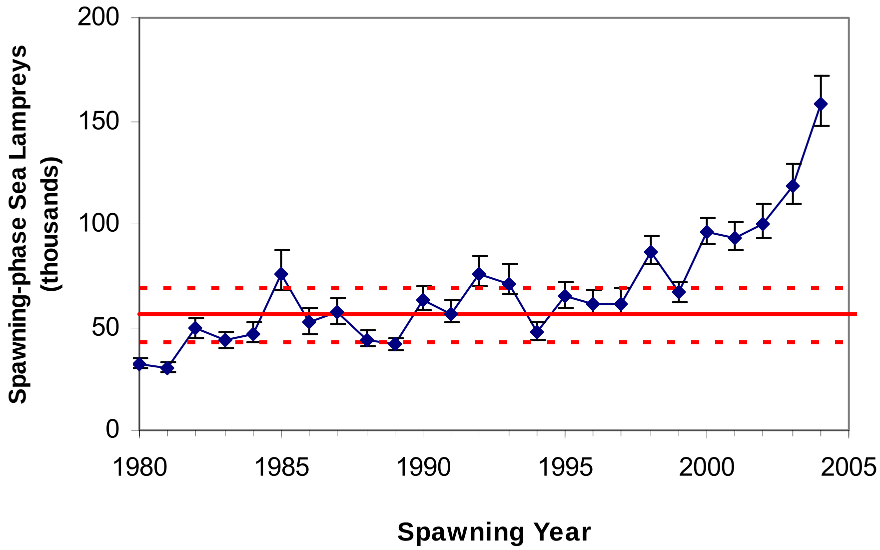


Figure 4. *Number of spawning-phase sea lampreys in Lake Michigan estimated from a regression model that extrapolates individual river trap catches to lake-wide abundance based on river discharge and treatment history (Mullett et al. 2003). The horizontal lines represent the target abundance for sea lampreys and confidence bounds (56,000 +/- 13,000) that will cause minimal mortality on lake trout as prescribed in the Fish Community Objectives (Eshenroder et al 1999a).*

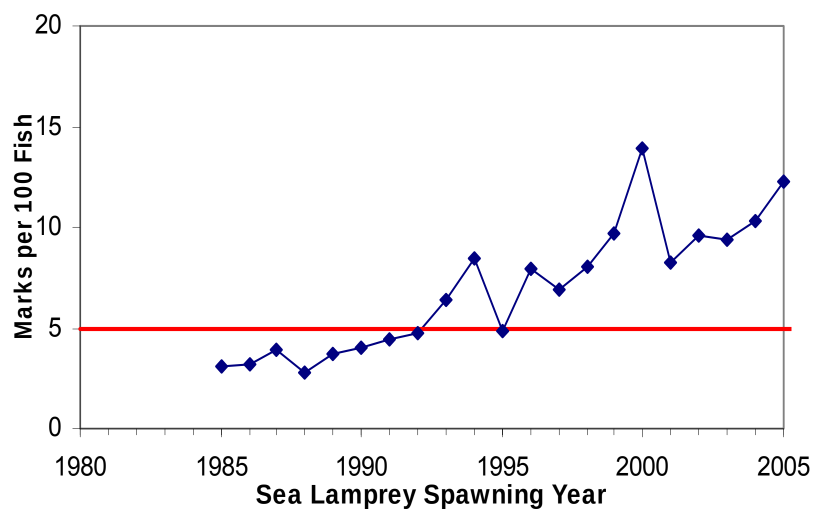


Figure 5*. Number of A1-3 marks per 100 lake trout size > 21 inches total length from standardized assessments during August-November. These data are plotted on the year of observation plus one to allow direct comparison to estimates of spawning-phase sea lamprey abundance (Figure 4).*

Impediments addressed: *Mortality too high.*

Objectives addressed: *Increase adult abundance, Build spawning populations.*

Evaluation

A variety of assessment methods will be used to evaluate progress toward reaching the objectives of this plan. Some evaluations, such as the spring and fall lake trout assessments described in the Lakewide Assessment Plan (LWAP) for Lake Michigan (Scheenburger et al. 1997), are already in place. The current LWAP protocol will have to be modified to respond to the changes in stocking locations recommended here.

Outputs from SCAA models are currently available for statistical districts in Michigan waters and should be used to evaluate progress toward achieving population objectives. Outputs of interest include population size, spawner biomass, spawner-stock-biomass per recruit, and mortality separated into sea lamprey, natural and fishing components. Models should be developed as soon as possible for populations in other statistical districts.

Fishery agencies should make long term commitments to evaluation to ensure that this restoration program will have adequate information available to guide future decisions. Agency responsibility for conducting assessments will be discussed and assigned at the winter meetings of the Lake Michigan Technical Committee. Agencies should assist each other in conducting assessments as cooperation will be critical when crises occur regarding mechanical failure of vessels, availability of crew, and constraints caused by inadequate funding.

Evaluation methods for each objective include the following:

<u>Objective 1 (Increase genetic diversity):</u> The 1985 Plan recommended securing, stocking, and evaluating a variety of lake trout strains to determine those best suited for colonizing Lake Michigan. To date, the strains reared and introduced have been primarily lean forms that are best adapted for shallow water habitat. The analysis of restoration impediments clearly indicated that future stocking should use a variety of strains to maximize colonization of not only shallow, but also intermediate, and deepwater habitats where the important lake trout populations were historically located. The National Fish Hatcheries currently contain a suite of lean strains and one deep-water strain. All fingerling and yearling lake trout stocked should have a fin clip to facilitate selective fisheries as recommended under harvest practices and at least 50 % with a CWT in order to evaluate strain performance, movement and stocking location effects. Fish stocked into refuges and First-priority areas should have a distinctive CWT series in order to evaluate their performance through the field measures used to achieve the Objectives below. All strains should be tagged for at least five consecutive years and recapture frequencies should be evaluated for 12 years after the last year-class is stocked. Reproductive performance of the different strains should be assessed genetically using mixed stock analysis of recovered wild fish.

<u>Objective 2 (Increase overall abundance):</u> The CPUE estimates from spring graded-mesh gill-net assessments, as described in LWAP, will be used to evaluate progress toward reaching the target CPUEs for refuges and high-priority areas. All CPUE estimates must be accompanied by variance statistics so as to disclose the level of uncertainty.

Objective 3 (Increase adult abundance): Annual CPUE estimates from the spring, graded-mesh gill net survey will serve as an index of overall status of the adult population. Fall spawner-abundance assessments will be used to measure progress toward reaching the benchmark CPUE of >50 fish/ 1000 ft on designated spawning reefs. The frequency of spawner-abundance assessments on designated reefs in fall will vary from annually to once every three to five years depending on the age composition of the spawner population on each reef. Once SCAA models are developed for non-treaty waters, estimates of spawner population biomass or potential egg deposition should be tracked for these areas as well.

Objective 4 (Build spawning populations): Evaluation procedures same as for Objective 3 above.

Objective 5 (Detect egg deposition): Standard egg bags will be place onto spawning reefs to measure egg deposition as per Perkins and Krueger (1994). Bags will be retrieved and live and dead eggs counted. Selection of reefs will be made by the Lake Trout Task Group and agencies will be tasked to perform the work. Egg thiamine levels will be monitored from a minimum of 16 mature females collected from representative spawning locations throughout the lake on an annual basis, and when possible egg thiamine levels will be measured in eggs collected in egg bags.

Objective 6 (Detect recruitment of wild fish): Recruitment of juvenile and adult wild fish will be detected with the spring, graded-mesh gill net survey from 2 to 4 years after natural reproduction is first detected. Beam trawling in spring and summer will be used at the Mid-Lake Reef complex and on designated reefs in northern waters to sample for young of the year and will provide more immediate detection of recruitment. The ongoing fall forage trawl surveys by the U.S. Geological Survey and the new summer trawl surveys proposed by the U.S. Fish and Wildlife Service will be used to detect older wild juveniles (2-6 yrs of age). The absence of fin clips, slower growth as indicated on calcified structures, smaller sizes at age-1, and color differences (wild fish are darker) will be used to differentiate wild fish from stocked fish. A tissue sample should be collected from all suspected wild fish for genetic determination of parental origin.

<u>Objective 7 (Achieve restoration):</u> Same assessments described above in Objective 6.

Plan Implementation

Successful implementation of this plan is completely dependent on the willingness of the participating agencies to cooperatively assume and carry out their respective responsibilities for producing hatchery fish, controlling fishing mortality, reducing sea lamprey populations, and collecting, processing, and jointly analyzing data. The Lake Trout Task Group will annually review progress toward achievement of Plan objectives and provide a verbal and written report annually to the Lake Michigan Technical Committee at the March Upper Lakes meeting. The Task Group, working through the Technical Committee, may periodically propose refinements of the Plan to the Lake Committee. The agencies should periodically re-evaulate the plan to gauge progress toward the population "Objectives" and to make recommendations to the Lake Committee for needed improvements when new information suggests that changes are warranted.

Reporting

Data collected annually during all lake trout assessments should be archived in a single, standardized, relational database and be accessible only to participating agencies. Data will be used to develop unbiased measures, incorporated in SCAA models, and compared to biological benchmark values stated in the Objectives section. The Task Group should establish timelines, procedures, and standards for data collection, assembly, analysis, and reporting. Biological measures related to "Objectives" selected for annual tracking and incorporation into models will be reported by some meaningful geographical unit as specified by the Task Group. The Task Group will create a standard format for brief written annual reports to the Technical and Lake Committees. More detailed reports will be prepared and presented to the Lake Committee every three to five years. These reports will contain proposals for adaptive changes to the Plan as circumstances dictate.

Review and Revision

In 2020, a major review and revision of the plan will be conducted based on new information obtained from annual evaluations. This scheduled review will allow the plan to respond to changes in the lake that might have occurred (e.g., invasions of new exotic species) and to incorporate an improved understanding of community ecology and the impediments facing lake trout restoration. As a result, new objectives and new actions may be specified at this time.

Research and Information Needs

To overcome the impediments to lake trout restoration, further research is required. The following is a list of research questions that will advance our understanding of successful lake trout restoration in Lake Michigan.

1. To what extent are bottlenecks in recruitment created by limited egg deposition and mortality during lake trout egg and fry stages?
2. What is the potential of early life-stage stocking to increase the effective number of lake trout stocked in Lake Michigan and/or improve reproductive responses and homing responses?
3. What are the important spawning cues (e.g., pheromones, physical characteristics of a site) used by lake trout to select spawning locations to successfully reproduce? Can attractants be developed to improve / increase lake trout use of appropriate spawning sites?
4. What are the movement patterns of lake trout at different life-stages among lake regions in Lake Michigan?
5. What phenotypes of lake trout are best suited for reintroduction? What strains are contributing to spawning (i.e. eggs, fry, and unclipped adults recovered)?

6. What impacts do gobies have on lake trout and what is their population trajectory on spawning reefs.
7. What is the level of egg deposition, strain use, and potential for egg predation at the Mid-Lake Reef?
8. What is the level of young-of-year production and mortality at the Mid-Lake Reef?
9. What are the absolute population size, spawner biomass, mortality rate, and age structure of lake trout stocks in each management unit in Lake Michigan?
10. What is the threshold egg thiamine level above which lake trout fry survival is no longer impaired?
11. What is the threshold level of thiaminase in alewife below which EMS no longer impairs lake trout fry survival?
12. What is the source of thiaminase in Lake Michigan and what ecosystem conditions enhance its availability to alewife and rainbow smelt?
13. What is the annual and regional variation in thiamine levels of lake trout and the relationship between thiamine and EMS?
14. Are there for thiaminase resistant lake trout, and can tools be developed to screen for such individuals? Can a lake trout broodstock be developed that is genetically resistant to EMS?
15. What factors are limiting the population growth or reestablishment of lake herring and deepwater coregonines in Lake Michigan?

Constraints to the Implementation of the Plan

Hatchery Production Capability

The present production capability of U.S. Fish and Wildlife Service hatcheries in the upper Great Lakes is less than the number of lake trout required by the plan. The

Service historically has reared most of the lake trout stocked into Lake Michigan and is currently operating four broodstock and three production hatcheries at maximum capacity (about 3.3 million yearlings) but is unable to meet the restoration needs of Lakes Michigan and Huron (8.1 million yearlings). Capital improvements to increase production at these facilities are now underway and could result in increasing production to about 5.1 million fish if completely funded (uncertain). However, without major new federal expansion or increased contributions of lake trout from state and tribal hatcheries, the significant increases in lake trout stocking required by this plan cannot be met. New hatchery construction, if deemed necessary, will require several years of planning and construction before additional fish would be available for stocking. These new fish will not contribute to the parental stock until five to seven years after they are stocked, hence increased production from hatchery expansions will not affect restoration efforts for many years. This plan recognizes these current limitations; its goals and objectives are intended to concentrate current (2.3 million yearlings/year) and future hatchery production available for Lake Michigan into areas where the prospects for natural reproduction are greatest.

Sport and Commercial Lake Trout Harvest

The ideal strategy to reestablish an extirpated species is to dedicate all available hatchery fish to the reestablishment goal and provide complete protection from exploitation until sustaining stocks are established. Because harvest of lake trout is an important cultural activity for both state and tribal fishers, the Lake Michigan Committee will have to balance societal needs for harvest with restoration goals. This revised plan adopts strategies that concentrate the available hatchery fish to the areas where restoration is most likely to succeed. The production of lake trout currently available from National Fish hatcheries will not meet the requirements for rehabilitation and the demand for harvest in Lake Michigan. To meet these conflicting demands, non-federal hatcheries could be dedicated to rear lake trout specifically to meet harvest demands.

Literature Cited

Bergstedt, R.A., Argyle, R.L., Seelye, J.G., Scribner, K.T., and Curtis, G.L. 2003. In situ determination of the annual thermal habitat use by lake trout (*Salvelinus namaycush*) in Lake Huron. *J. Gt. Lakes. Res*. 29 (Suppl. 1): 347-361.

Bronte, C.R. 1993. Evidence of spring spawning lake trout in Lake Superior. *J. Gt. Lakes Res*. 19: 625-629.

Bronte, C.R. and 12 co-authors. 2003a. Success of current strategies to re-colonize lake trout spawning reefs in northern Lake Michigan. Final report, Project 1999.6, Great Lakes Fishery Trust.

Bronte, C.R., Ebener, M.P., Schreiner, D.R., DeVault, D.S., Petzold, M.M., Jensen, D.A., Richards, C., and Lozano, S.J. 2003b. Fish community change in Lake Superior, 1970-2000. *Can. J. Fish. Aquatic. Sci.* 60: 1552-1574.

Bronte, C. R., Jonas, J., Holey, M.E., Eshenroder, R.L., Toneys, M.L., McKee, P., Breidert, B., Claramunt, R.M., Ebener, M.P., Krueger, C.C., Wright, G., and Hess, R. 2003c. *Possible impediments to lake trout restoration in Lake Michigan.* Lake Trout Task Group report to the Lake Michigan Committee, Great Lakes Fishery Commission.

Bronte, C.R., Schram, S.T., Selgeby, J.H., and Swanson, B. L. 2002. Reestablishing a spawning lake trout population in Lake Superior with fertilized eggs in artificial turf incubators. *N. Am. J. Fish. Manage*. 22:796-805.

Brown, E.H., Jr., Eck, G.W., Foster, N.R. Horrall, R.M. and Coberly, C. E. 1981. Historical evidence for discrete stocks of lake trout (*Salvelinus namaycush*) in Lake Michigan. *Can. J. Fish. Aquat. Sci*. 38:1747-1758.

Brown, S.B., Fitzsimons, J.D., Palace, V.P., and Vandenbyllaardt, L. 1998. Thiamine and early mortality syndrome in lake trout (*Salvelinus namaycush*). Pages 18-25 *in* G. McDonald, J. D. Fitzsimons, and D. C. Honeyfield, editors. Early Life stage mortality syndrome in fishes of the Great Lakes and the Baltic Sea. American Fisheries Society, Symposium 21, Bethesda, Maryland.

Brown, S.B. and Honeyfield, D.C. 2004. Early mortality syndrome workshop. Sept 8-9, 2004. Great Lakes Fishery Commission Research Status Report.

Coberly, C.E., and Horrall, R.M. 1982. A strategy for re-establishing self-sustaining lake trout stocks in Illinois waters of Lake Michigan. Institute for Environmental Studies, Marine Studies Center, University of Wisconsin, Madison. Rp. No. 42.

Conner, D.J., Bronte, C.R., Selgeby, J.H. and Collins, H.L. 1993. Food of salmonine predators in Lake Superior. Gt. Lakes Fish. Comm. Tech. Rep. No. 59.

Dawson, K.A., Eshenroder, R.L., Holey, M.E., and Ward, C. 1997. Quantification of historic lake trout (*Salvelinus namaycush*) spawning aggregations in Lake Michigan. *Can. J. Fish. Aquat. Sci*. 54:2290-2303.

Dorr, J.A., III, O' Conner, D.V., Foster, N.R., and Jude, D.J. 1981. Substrate conditions and abundance of lake trout eggs on a traditional spawning area in southeastern Lake Michigan. *N. Am. J. Fish. Manage*. 1:165-172.

Elrod, J.H., O'Gorman, R., Schneider, C.P., and Schaner, T. 1996. Geographical distributions of lake trout strains stocked in Lake Ontario *J. Gt. Lakes Res*. 22: 871-883.

Eshenroder, R.L. and Amatangelo, K.L. 2002. Changes in catch per unit effort of spawning lake trout in Lake Michigan during the 1900s with emphasis on the population collapse of the 1940s. Great Lakes Fishery Commission Technical Report 65.

Eshenroder, R.L., Holey, M.E., Gorenflo, T.K., and Clark, R.D. 1999a. Fish-community objectives for Lake Michigan. Gt. Lakes. Fish. Comm. Spec. Pub. 99-1. 56 p.

Eshenroder, R.L., Peck, J.W., and Olver, C.H. 1999b. *Research priorities for lake trout restoration in the Great Lakes: a 15-year retrospective*. Great Lakes Fishery Commission Technical Report 64.

Eschmeyer, P.H. 1956. The early life history of lake trout in Lake Superior. Misc. Publ. 10, Michigan Dept. Cons., Institute for Fisheries Res., Ann Arbor.

Eschmeyer, P.H. 1957. The near extinction of lake trout in Lake Michigan. *Trans. Am. Fish. Soc.* 85:102-119.

Fitzsimons, J. D., and S. B. Brown. 1998. Reduced egg thiamine levels in inland and Great Lakes lake trout and their relationship with diet. Pages 160-171 *in* G. McDonald, J. D. Fitzsimons and D. C. Honeyfield, editors. Early life stage mortality syndrome in fishes of the Great Lakes and the Baltic Sea. American Fisheries Society, Symposium 21, Bethesda, Maryland.

Fournier, D. and Archibald, C.P. 1982. A general theory for analyzing catch at age data*. Can. J. Fish. Aquat. Sci*. 39:941-949.

Goede, R.W. 1991. Fish health/condition assessment procedures. Part 1. Utah Division of Wildlife Resources, Logan.

Goode, G.B. 1884. Natural history of useful aquatic animals, p. 485-497. *In* G.B. Goode and associates. The fisheries and fishery industries of the United States. Section 1. U.S. Commission of Fish and Fisheries, Washington DC.

Grewe, P.M., Krueger, C.C., Marsden, J.E., Aquandro, C.F., and May, B. 1994. Hatchery origins of naturally produced lake trout fry captured in Lake Ontario: temporal and spatial variability based on allozyme and mitochondrial DNA data. *Trans. Am. Fish. Soc.* 123:309-320.

Griffith, B., Scott, J.M., Carpenter, J.W., and Reed, C. 1989. Translocation as a species conservation tool: status and strategy. *Science* 245:477-480.

Hansen, M.J. [ED.] 1996. *A lake trout restoration plan for Lake Superior*. Great Lakes Fish. Comm.

Hansen, M.J. 1999. Lake trout in the Great Lakes: basinwide stock collapse and binational restoration. *In* Great Lakes Fisheries Policy and Management. *Edited by* W.W. Taylor and C.P. Ferreri. Michigan State University Press, East Lansing, MI. pp. 417-454.

Harvey, C.J., Schram, S.T., and Kitchell, J.F. 2003. Trophic relationships among lean and siscowet lake trout in Lake Superior. Trans. Am. Fish. Soc. **132**: 219-228.

Healey, M.C. 1978. The dynamics of exploited lake trout populations and implications for management. Am. J. Wildlife Manage. 42:307-328.

Hewitt, O.H. 1967. *The wild turkey and its management.* Washington, D.C: The Wild. Soc.

Hilborn, R. and Walters, C.J.. 1992. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty.* Routledge, Chapman & Hall, Inc., New York, NY.

Hile, R., Eschmeyer, P.H., and Lunger, G.F. 1951. Decline of the lake trout fishery in Lake Michigan. *U.S. Fish and Wildlife Service Fisheries Bulletin* 52:77-95.

Holey, M. E. 2000. *Broodstock management of wild Great Lakes lake trout and brook trout in the National Fish Hatchery system*. U.S Fish and Wildlife Service Region 3, 22p.

Holey, M.E., Rybicki, R.W., Eck, G.W., Brown, E.H., Jr., Marsden, J.E., Lavis, D.S., Toneys, M.L., Trudeau, T.N., and Horrall, R.M.. 1995. Progress toward lake trout restoration in Lake Michigan. *J. Gt. Lakes Res*. 21 (Suppl. 1): 128-151.

Honeyfield, D.C., Hinterkopf, J.P., Fitzsimons, J.D., Brown, S.B., Tillitt, D.E., and

Zajicek, J. 2005. Development of thiamine deficiencies and early mortality syndrome in lake trout by feeding experimental and feral fish diets containing thiaminase. Journal of Aquatic Animal Health. 17:in press.

Johnson, J.E., He, J.X., Woldt, A.P., Ebener, M.P., and Mohr, L.C. 2004. Lessons in rehabilitation stocking and management of lake trout in Lake Huron. Am. Fish. Soc. Sym. 44:161-175.

Jonas, J.L., Claramunt, R.M., Fitzsimons, J.D., Marsden, J.E., and Ellrott, B.J. 2005. Estimates of egg deposition and the effects of lake trout egg predators in northern Lake Michigan, Parry Sound (Lake Huron), and Lake Champlain. *Can. J. Fish. Aquat. Sci*. (in press).

Jude, D.J., Klinger, S.A. and Enk, M.D. 1981. Evidence of natural reproduction by planted lake trout in Lake Michigan. *J. Gt. Lakes Res.* 7:57-61.

Kolick, J.F., and Jones, M.L. 1999. *Pacific salmonines in the Great Lakes basin. In* Great Lakes Fisheries Policy and Management. *Edited by* W.W. Taylor and C. P. Ferreri. Michigan State University Press, East Lansing.

Krueger, C.C., and M. Ebener. 2004. Restoration of lake trout in the Great Lakes: past lessons and future challenges. Pages 37-56 *in* J.M. Gunn, R.J. Stedman, and R.A. Ryder, editors. Boreal Shield watersheds. Lake trout ecosystems in a changing environment. Lewis Publishers, Boca Raton, Florida.

Krueger, C.C., Gharrett, A.J., Dehring, T.R., and Allendor, F.W. 1981. Genetic aspects of fisheries restoration programs. *Can. J. Fish. Aquat. Sci.* 38:1877-1881.

Krueger, C.C., Horrall, R.M., and Gruenthal, H. 1983. Strategy for the use of lake trout strains in Lake Michigan. Wisc. Dep. Nat. Res. Admin. Rep.17.

Krueger, C.C., and Ihssen, P. E. 1995. Review of genetics of lake trout in the Great Lakes: history, molecular genetics, physiology, strain comparisons, and restoration management. *J. Gt. Lakes Res***.** 21 (Suppl. 1):348-363.

Krueger, C.C., Perkins, D.L., Mills, E.L., and Marsden, J.E. 1995. Predation by alewives on lake trout fry in Lake Ontario: role of an exotic species in preventing restoration of a native species. *J. Gt. Lakes Res*. 21 (Suppl. 1): 458-469.

Krueger, C.C., Swanson, B.L., and Selgeby, J.H. 1986. Evaluation of hatchery-reared lake trout for reestablishment of populations in the Apostle Islands region of Lake Superior, 1960-84. In *Fish Culture in Fisheries Management*, ed. R.H. Stroud, pp. 93-107. Bethesda, MD: American Fisheries Society.

Lawrie, A.H., and Rahrer, J.F. 1972. Lake Superior: effects of exploitation and introduction on the salmonid community. J. Fish. Res. Board Can. 29: 765-776.

Lavis, D.S., Henson, M.P., Johnson, D.A., Koon, E.M., and Ollila, D.J. 2003. A case history of sea lamprey control in Lake Michigan: 1979 to 1999. *J. Gt. Lakes Res*. 29 (Suppl. 1): 584-598.

LMLTTC (Lake Michigan Lake Trout Technical Committee). 1985. A draft lakewide plan for lake trout restoration in Lake Michigan. In *Minutes Lake Michigan Committee (1985 annual minutes),* Ann Arbor, MI, Great Lakes Fishery Commission, March 19, 1985.

Marsden, J.E. 1994. Spawning by stocked lake trout on shallow, near-shore reefs in southwestern Lake Michigan. *J. Gt. Lakes Res*. 20:377-384.

Marsden, J. E., Ellrott, B., Claramunt, R., Jonas, J. L., and Fitzsimons, J. F. In review. A comparison of lake trout spawning, emergence, and habitat use for lakes Michigan, Huron (Parry Sound) and Champlain. *J. Gt. Lakes Res.*

Marsden, J.E. and Janssen, J. 1997. Evidence of lake trout spawning on a deep reef in Lake Michigan using an ROV-based egg collector. *J. Gt. Lakes Res*. 23:450-457.

Marcquenski, S.V., and Brown, S.B.. 1997. Early mortality syndrome in the Great Lakes. Pages 135-152 *in* R. M. Rolland, M. Gilbertson, R. E. Peterson, editors. Chemically induced alterations in functional development and reproduction in fishes. SETAC (Society of Environmental Toxicology and Chemistry), Pensacola, Florida.

Methot, R.D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data, p. 259-277. In: L. Low (ed.), Proceedings of the symposium on applications of stock assessment techniques to Gadids. Int. North Pac. Fish. Comm. Bull. 50.

Methot, R.D. 2000. Technical description of the stock synthesis assessment program. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-43, 46 p.

Miller, L.M., and Kapuscinski, A.R. 2003. Genetic guidelines for hatchery supplementation programs, p. 329-355. *In* E. Hallerman, editor. Population genetics: principles and practices for fisheries scientists. American Fisheries Society, Bethesda, Maryland.

Modeling Subcommittee, Technical Fisheries Committee. 2004. *Summary Status of Lake Trout and Lake Whitefish Populations in the 1836 Treaty-Ceded Waters of Lakes Superior, Huron and Michigan in 2001, with recommended yield and effort levels for 2003.* Technical Fisheries Committee, 1836 Treaty-Ceded Waters of Lakes Superior, Huron and Michigan.

Moore, S.A., and Bronte, C.R. 2001. Delineation of sympatric morphotypes of lake trout in Lake Superior. *Trans. Am. Fish. Soc.* 130:1233-1240.

Mullett, K.M., Heinrich J.W., Adams, J.V., Young, R.J., Henson, M.P., McDonald, R.B., and Fodale, M.F. 2003. Estimating lake-wide abundance of spawning-phase sea lampreys (*Petromyzon marinus*) in the Great Lakes: Extrapolating from sampled streams using regression models. J. Great Lakes Res. 29 (Supplement 1): 240-252.

NRC (Committee on Fish Stock Assessment, National Research Council). 1998. Improving fish stock assessments. National Academy Press. Washington D.C. 177 p.

O'Gorman, R., Elrod, J. H., and Schneider, C. P. 1998. Reproductive potential and fecundity of lake trout strains in southern and eastern waters of Lake Ontario, 1977-1994. J. Great Lakes Res. 24(1):131-144.

Page, K.S. 2001. Genetic diversity and interrelationships of wild and hatchery lake trout in the upper Great Lakes: inferences for broodstock management and development of restoration strategies. M.S. Thesis, Michigan State University, East Lansing, Michigan.

Page, K.S., Scribner, K.T., and Burnham-Curtis, M.K. Genetic diversity of wild and hatchery lake trout populations: relevance for management and restoration in the Great Lakes. *Trans. Amer. Fish. Soc.* 133:674-691.

Page, K.S., Scribner, K.T., Bennett, K.R., Garzel, L.M., and Burnham-Curtis, M.K. 2003. Genetic assessment of strain-specific sources of lake trout recruitment in the Great Lakes. *Trans. Amer. Fish. Soc.* 132:877-894.

Peck, J. W. 1986. Dynamics of reproduction by hatchery lake trout on a man-made spawning reef. *J. Great Lakes Res.* 12:293-303.

Perkins, D.L., and Krueger, C.C. 1994. Design and use of mesh bags to estimate deposition and survival of fish eggs in cobble substrate. *N. Am. J. Fish. Manage.* 14:866-869.

Perkins, D.L., Fitzsimons, J.D., Marsden, J.E., Krueger, C.C., and May, B. 1995. Differences in reproduction among hatchery strains of lake trout in eight spawning areas in Lake Ontario: genetic evidence from mixed-stock analysis. *J. Gt. Lakes Res.* 21(Supplement 1):364-374.

Quinn, T.J. and Deriso, R.B. 1999. *Quantitative Fish Dynamics*. Oxford University Press. New York. 542 pp.

Reid, D.M., Anderson, D.M., and Henderson, B.A. 2001. Restoration of Lake Trout in Parry Sound, Lake Huron. *N. Amer. J. Fish. Manage.* 21:156-169.

Reisenbichler, R.R., Utter, F.M., and Krueger, C.C. 2003. Genetic concepts and uncertainties in restoring fish populations and species. *In* Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems, pp. 000-000. Bethesda, Maryland:Am. Fish. Soc.

Royce, W.F. 1951. Breeding habits of lake trout in New York. U.S. Fish and Wildlife Service Fish. Bull. 52:59-76.

Rybicki, R.W. 1991. *Growth, mortality, recruitment and management of lake trout in eastern Lake Michigan.* Michigan Department of Natural Resources, Fisheries Research Report 1863. Ann Arbor, MI.

Ryder, R.A. and Edwards, C.J. [eds.]. 1985. A conceptual approach for the application of biological indicators of ecosystem quality in the Great Lakes Basin. Intern. Joint Comm. And Great Lakes. Fish. Comm., Windsor, ON.

Sarrazin, R., and Legendre, S. 2000. Demographic approach to releasing adults versus young in reintroductions. *Cons. Biol.* 14:488-500.

Selgeby, J.H. and Hoff, M.H. 1996. *Seasonal bathymetric distributions of 16 fishes in Lake Superior, 1958-75.* Biological Science Report 7, National Biological Service 14 p.

Schneeberger, P., Toneys, M., Elliot, R., Jonas, J., Clapp, D., Hess, R., and Passino-Reader, D. 1997. *Lakewide assessment plan for Lake Michigan fish communities*. Lake Michigan Technical Committee, Great Lakes Fishery Commission. .http://www.glfc.org/pubs/SpecialPubs/lwasses01.pdf

Smith, H.M., and Snell, M.M. 1891. *The fisheries of Lake Michigan*, p. 71-204. *In* H.M. Smith, M.M. Snell, and J.W. Collins (ed). A review of the fisheries of the Great Lakes in 1885. U.S. Commission of Fish and Fisheries. Report of the Commissioner for 1887.

Smith, R. 1908. Whitefish and trout in Lake Michigan, p. 25-29. *In* Report of the State Commissioners of Illinois 1906-1908.

Strang, J.J. 1855. Some remarks on the natural history of the Beaver Islands, Michigan. In 9th *Ann. Rep. Board Regents Smithsonian Inst.*, pp. 282-288. Washington, D.C.: A.O.P. Nicholson.

True, F.W. 1887. The fisheries of the Great Lakes, p. 631-673. *In* G.B. Goode and associates. The fisheries and fishery industries of the United States. Section 2. U.S. Commission of Fish and Fisheries, Washington DC.

United States vs. State of Michigan. 2000. Consent Decree, August 8, 2000. U.S. District Court, Western District of Michigan, Southern Division. Case No. 2:73 CV 26.

Van Oosten, J., and Eschmeyer, P.H. 1956. *Biology of young lake trout,* Salvelinus namaycush*, in Lake Michigan.* Res. Rep., U.S. Fish and Wildlife Service 42.

Wagner, W.C. 1981. Reproduction by planted lake trout in Lake Michigan. *N. Am. J. Fish. Manage*. 1:159-164.

Ward, C., Eshenroder, R.E., and Bence, J.R. 2000. Relative abundance of lake trout and burbot in the main basin of Lake Michigan in the early 1930s. *Trans. Amer. Fish. Soc.* 129:282–295.

Wells, L. and McLain, A.L. 1973*. Lake Michigan –mans effects on native fish stocks and other biota.* Gt. Lakes Fish. Comm., Report No. 20.

Wolf, C.M., Griffith, B., Reed, C., and Temple, S.A. 1996. Avian and mammalian translocations: update and reanalysis of 1987 survey data. *Cons. Biol.* 10:1142-1154.

The Lake Michigan Lake Trout Task Group

Brian Breidert, Indiana Department of Natural Resources, Michigan City, IN

Charles Bronte (Chairperson), U.S. Fish and Wildlife Service, New Franken, WI

Mark Ebener, Chippewa/Ottawa Resource Authority, Sault Ste. Marie, MI

Randy Eshenroder, Great Lakes Fishery Commission, Ann Arbor, MI

Mark Holey, U.S. Fish and Wildlife Service, New Franken, WI

Jory Jonas, Michigan Department of Natural Resources, Charlevoix, MI

Charles Krueger, Great Lakes Fishery Commission, Ann Arbor, MI

Steve Lenart, Little Traverse Bay Band of Odawa Indians, Harbor Springs, MI

Charles Madenjian, U.S. Geological Survey, Ann Arbor, MI

Archie Martell, Little River Band of Ottawa Indians, Manistee, MI

Patrick McKee, Wisconsin Department of Natural Resources, Sturgeon Bay, WI

Erik Olsen, Grand Traverse Band of Ottawa and Chippewa Indians, Suttons Bay, MI

Paul Peeters, Wisconsin Department of Natural Resources, Sturgeon Bay, WI

Steve Robillard, Illinois Department of Conservation, Des Plaines, IL

Michael Toneys, Wisconsin Department of Natural Resources, Sturgeon Bay, WI

Greg Wright, Chippewa/Ottawa Resource Authority, Sault Ste. Marie, MI